DEVELOPMENT OF ULTRA HIGH FREQUENCY ENERGY HARVESTER USING CIRCULAR SPIRAL ARRAY WITH CORPORATE FEEDING

by

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LIST OF SYMBOLS

ε_r	Dielectric Constant
ε_{eff}	Effective Dielectric Constant
Ω	Ohms (Impedance)
β	Propagation Constant
λ_0	The Wavelength in Free Space
λ_g	The Guided Wave Length
μ	Magnetic Permeability
ω	Resonance Frequency
ρ	Fill Ratio
ρ_c	Copper Resistivity
δ	Skin Depth
σ	Copper Conductivity
η	Conversion efficiency
B	Magnetic Flux Density
B_m	The Susceptance of the Fringing Field Capacitance of the Microstrip
C_n	Various Coefficient
C_l	Capacitance of the Microstrip
C	Capacitance
C_p	Parasitic Capacitance
C_{sub}	Substrate Capacitance
C_j	Junction Capacitance
c	Speed of Light

d_{avg}	Average Diameter
d_i	Inner Diameter
d_o	Outer Diameter
E	Electric Field
F	Resonant Frequency
J	Electric Current Density
G_{rm}	Microstrip Radiation Conductance
G_s	Gain of Standard Antenna
G_T	Gain of Tested Antenna
H	Magnetic Field
h	Height of Substrate
I_{BV}	Bias Current
K_g	Presence of Ground
L	Inductance
l	Physical Length
l_{eq}	Extra Length of Microstrip Line
N	Number of Turn
N_i	Ideally factor
W	Width
P_T	Power Received by tested antenna
P_S	Power Received by standard antenna
P_{DC}	Output Power
P_{RF}	RF Input Power
R	Resistance
R_{DC}	DC Resistance

R_S	Skin Effect
R_i	Inner Radius
S	Spacing Between Turns
t_c	Thickness of Copper
Z_0	Microstrip Characteristic Impedance

LIST OF ABBREVIATIONS

ADS	Advanced Design System
AC	Alternating Current
CST	Computer Simulation Technology
DC	Direct Current
DTV	Digital Television
dB	Decibel
GSM	Global System for Mobile
LTE	Long Term Evolution
LHCP	Left Hand Circular Polarized
LED	Light Emitting Diode
PZT	Lead Zirconate Titanate
PVDF	Polyvinylidene Fluoride
PCB	Printed Circuit Board
RF	Radio Frequency
RHCP	Right Hand Circular Polarized
SMA	Sub Miniature version A
SPICE	Simulation Program with Integrated Circuit Emphasis
TV	Television
TEG	Thermoelectric Generator
WSN	Wireless Sensor Node

PEMBANGUNAN PENUAI TENAGA FREKUENSI ULTRA TINGGI MENGGUNAKAN SUSUNAN LINGKARAN BULAT DENGAN PENYUAPAN KORPORAT

ABSTRAK

Tesis ini adalah untuk mereka bentuk struktur antena alternatif yang boleh meningkatkan gandaan antena, jumlah tenaga penuai dan membekal kuasa tinggi semasa penerusan. Kajian ini menghasilkan voltan mantap pada frekuensi 956 MHz untuk sistem penuai tenaga RF. Reka bentuk tentang antena lingkaran bulat dilakukan dengan menggunakan perisian Computer Simulation Technology (CST) dan perisian Advanced Designed System (ADS). Antena lingkaran bulat disambungkan dengan litar penerus untuk menukarkan isyarat masukan tenaga RF yang diterima daripada bentuk arus ulang-alik (AC) kepada bentuk arus terus (DC) . Tiga konfigurasi reka bentuk telah dicadangkan iaitu antena lingkaran bulat tunggal 1x2 susunan antena dan 2x4 susunan antena. Antena yang dicadangkan tersebut telah dibangunkan adalah berdasarkan kepada asas ciri-ciri antena seperti corak sinaran, kehilangan pulangan dan gandaan. 1x2 susunan antena dan 2x4 susunan antena telah direka bentuk dengan menggunakan kaedah penyuapan korporat yang dapat meningkatkan gandaan dan voltan keluaran penuai RF. Litar penerus daripada RF kepada arus terus (DC) adalah menggunakan diode *schottky* tanpa bias menukarkan tenaga penuaian yang diterima. Keputusan tersebut menunjukkan semua tiga jenis reka bentuk mempunyai gandaan pada 2.3 dBi, 3.2 dBi and 5 dBi manakala voltan keluaran yang dihasilkan adalah 17 mV, 59.4 mV dan 79 mV masing-masing. Ia didapati juga bahawa antena lingkaran bulat dapat membekalkan keluaran voltan DC tetap yang bermanfaat untuk aplikasi Ultra Frekuensi Tinggi.

DEVELOPMENT OF ULTRA HIGH FREQUENCY ENERGY HARVESTER USING CIRCULAR SPIRAL ARRAY WITH CORPORATE FEEDING

ABSTRACT

This thesis is to design an alternative antenna structure that will increase gain of the antenna, the amount of harvested energy and provide high power during rectification. The research works generate a steady output at a frequency of 956 MHz for RF energy harvesting system. The design of the circular spiral antenna is performed using Computer Simulation Technology (CST) and Advanced Designed System (ADS). The circular spiral antenna is integrated with the rectifying circuit to efficiently convert the input RF signal from alternating current (AC) to direct current (DC). Three configurations of the antenna designs were proposed namely single circular spiral antenna, 1x2 circular spiral antenna and 2x4 circular spiral antenna. The proposed antenna that had been developed is based on the basic antenna characteristic such as return loss, radiation pattern and gain. The 1x2 array antennas and 2x4 array antenna were designed using the corporate feed method that will increase the gain and enhanced the RF harvesting output voltage. The rectification of RF to DC energy used zero bias schottky diode that convert the incoming harvested energy. The results show that all the three design posses gain of 2.3 dBi, 3.2 dBi and 5 dBi, while the output voltage generated were 17 mV, 59.4 mV and 79 mV respectively. It is found also that the circular spiral antenna can provide a constant output DC voltage which is useful for UHF application.

CHAPTER ONE

INTRODUCTION

1.1 Background

Harvesting or so call scavenging of energy from ambient sources in the environment provides an opportunity for powering circuits in application. This idea have sparked interest in engineering field to design and create more new applications that will fully utilize energy harvesting for power. Applications of the energy harvesting, including the field of RFID tags (Barnett et al., 2009) such as portable medical devices (Paulo and Gaspar, 2010) and bio-telemetry (Huang et al., 2011) of biomedical engineering (Mutashar et al., 2014) are increasing rapidly. For example, one of the self-powered approaches used in RF energy harvesting is that when a circuit has been dormant for long period of time, the power inside might not be available to start up. Due to that, when design for the energy harvesting applications, it needs to be consider for "cold-start" capability where the circuit is boot at initialization process only by harvesting miniscale amount of wasted energy from the environment until sufficient power is available to energize the whole circuit.

As a result, energy harvesting not only enhances current application by eliminating the dependency on battery, but also creates a new device. Figure 1.1 shows the principle and architecture of RF energy harvesting system.

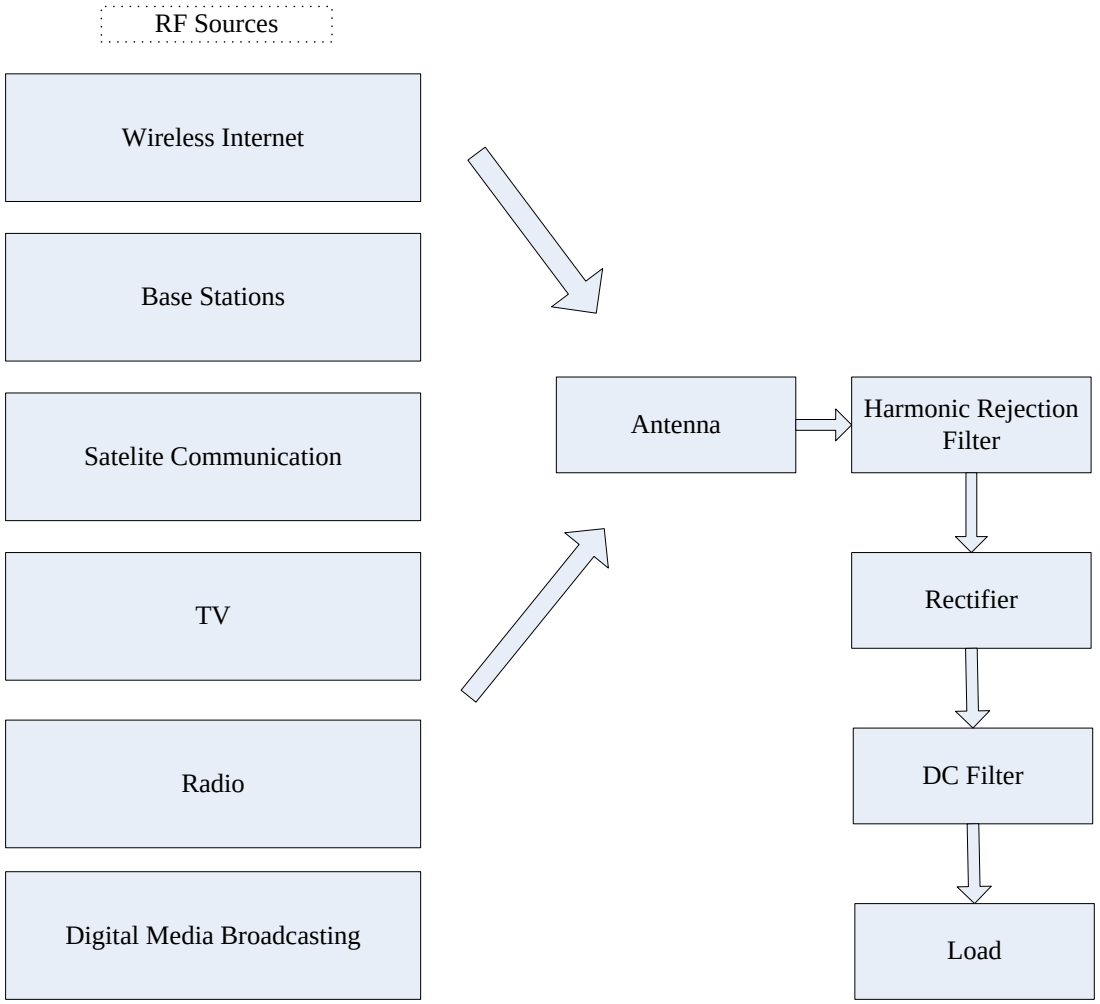

Figure 1.1: Principle of RF energy harvesting

1.2 Motivation

Energy supply has always been the key limiting to the lifetime of wireless sensor node (WSN). Commercial WSN is powered by the batteries. Due to this, batteries have limited lifespan and need to replace in due time. Besides that, battery maintenance becomes a problem when the wireless sensor nodes are placed inaccessible or hazards places (Al-Khayari et al., 2013). Lastly, deposition of battery will cause environmental issue.

The motivation behind this research is to design and evaluate a novel antenna and energy rectification system that will provide the idea of infinite power resources over a period of time to solve the problem of limited battery life (Hucheng et al., 2013). One of the solutions is by using RF energy harvesting method. This RF energy is transmitted in the form of microwave signal and is transmitting out from the various reliable electromagnetic resources for 24 hours (Borges et al., 2014) at any weather condition. By exploring to this possible alternative, thus making the WSN indefinitely self-sustaining (Yildiz, 2009) even when the battery is run out during night time. Other than that, the RF energy harvesting is convenient for the place that difficult to reach (Andia Vera et al., 2010)

Besides that, by using RF energy harvesting, it will overcome the limitation of the traditional energy harvesting. For example, the light harvesting need light sources, the vibration need motion to collect the energy. But for RF energy, it can be collected and recycling from the environment. Last but not least, energy harvesting can be used as backup generator in power systems, which helps to improve the reliability and prevent power interruptions. This project will explores some opportunities to design, simulate and develop a prototype of RF energy harvesting antenna for ultra high frequency application.

1.3 Problem Statement

Development of micro energy harvesting in power efficiency has sparked the interest in engineering field that will lead to create more useful application that will utilize energy harvesting for power. In this research, it is to build radio frequencies (RF) based technologies. Nowadays, there are a lot of devices and technologies that operate in the RF spectrum like cell phone, Wi-Fi etc. This energy

is constantly transmitting from television tower, radio or even cell phone. As a result, there is a lot of abundance of RF wave that will advantage the RF reception to extract power. This abundance energy can be harvested and uses it as a source of power. It is possible to collect all the energy and store it so that it can be used to power other circuits or device. For example, the energy that has been harvested can be used to recharge battery that is fast being depleted in cellular phone. The point in this harvesting method is the RF harvesting technique can be done in every second of the day.

But this compact antenna is suffering in terms of limitation of gain especially as a result of minimization. When the size of antenna is reduced, the amount of electromagnetic capturing will be reduced. Besides that, the normal antenna only can harvest the RF energy at the position of horizontal or vertical. This lead to the problem of the antenna will not able to function because the schottky diode of rectifier circuit receiving a low amount of power.

To overcome the resulting antenna problem, this research is mainly focusing on the feasibility study on the RF spiral antenna design and rectifier operating at 956 MHz frequency. The circular spiral antenna had proved to be useful for energy harvesting application by offering several advantages such as high gain, greater freedom of positioning, mechanical simplicity and cost effective.

1.4 Objectives

The aim of this research is to develop an alternative solution that different from existing antenna. It will provide a set of goals with lightweight, high gain and

more importantly of steady rectifier output. In order to accomplish the aim, this thesis concern around three objectives.

1. To develop and implement the circular spiral array antenna by using the corporate feed technique at 956 MHz in order to enhance the gain characteristic and maximize the harvested DC power in order to overcome the low amount of power at rectifier circuit.
2. To design and model the antenna structure with rectifying circuit that will have freedom on positioning to harvest ultra low power RF signal at 956 MHz operating frequency.
3. To verify the power during rectification and model the proposed spiral antennas (all the three presented designs), compare with the simulated and measurement results to validate the design structure.

1.5 Scope

The scope of this research is to design a high gain antenna that able to rectify the harvesting power as a goal. All the models were excited by using microstrip feed and the antenna layout design were fabricated on the RO4003C board from Roger Corporation. According to the board specification, the thickness is 0.813 mm, relative permittivity of 3.38 and loss tangent of 0.0021. The propose antenna were using Computer Simulation Technology (CST) microwave studio to model and simulate antenna design in order to understand the performance of the antenna. Besides that, Harmonic Balance approach in Advanced System Design (ADS) was used throughout the rectifier design and performance parametric study to obtain the optimum design.

Before the design, the important specifications were set and necessary mathematic equation to achieve the important specification was investigated. Different types of RF harvesting antenna design configuration were developed according to these specifications and their performance were compared in order to demonstrate the specific advantages of the proposed spiral antenna.

During the CST simulation, the characteristic of the antenna such as bandwidth, return loss, gain and the radiation pattern will be determined before fabrication. After that, modeling of the single element circular spiral antenna, 2 element antenna array and lastly 8 element spiral antenna array with corporate feed method was done. These spiral antenna models were done based on the lumped element equivalent calculation.

Finally, the proposed antenna were fabricated and measured. The measurement results were compared with the simulation results in order to observe the results. All results were analyzed, discussed and a conclusion is made based on the observation.

1.6 Thesis outline

This thesis is divided into five chapters. It is organized in such way as to properly layout the detail investigations and results of the research work. The background, problem statement, motivation and objective are presented in Chapter 1 with a summary of the thesis outline.

Chapter 2 is first briefly explains the general background of different type energy harvesting system. It follows by briefly explained on antenna theory and providing the review of existing RF energy harvesting antenna. The literature review